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Development of Hopfield Artificial Neural Network for Anomaly Detection in Environmental Gamma Radiation Background

Consortium on Nuclear Security Technologies (CONNECT) Q2 Report

Nuclear Science and Engineering Division

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Abstract

Environmental screening of gamma radiation consists of detecting weak nuisance and anomaly signal in the presence of strong and highly varying background. In a typical scenario, a mobile detector-spectrometer continuously measures gamma radiation spectra in short, e.g., one-second, signal acquisition intervals. The measurement data is a 2D matrix, where one dimension is gamma ray energy, and the other dimension is the number of measurements or total time. In principle, gamma radiation sources can be detected and identified from the measured data by their unique spectral lines. Detecting sources from data measured in a search scenario is difficult due to the highly varying background because of naturally occurring radioactive material (NORM), and low signal-to-noise ratio (S/N) of spectral signal measured during one-second acquisition intervals. The objective of this work is to explore *supervised* machine learning (ML) algorithms for development of a Hopfield Neural Network (HNN) in conjunction with an image processing algorithm for detection and identification of weak nuisances and anomalies events in the presence of a highly fluctuating background.

1. Introduction

Environmental screening of gamma radiation consists of detecting weak nuisance and anomaly signal in the presence of strong and highly varying background. In a typical scenario, a mobile detector-spectrometer continuously measures gamma radiation spectra in short, e.g., one-second, signal acquisition intervals. The measurement data is a 2D matrix, where one dimension is gamma ray energy, and the other dimension is the number of measurements or total time. In principle, gamma radiation sources can be detected and identified from the measured data by their unique spectral lines. Detecting sources from data measured in a search scenario is difficult due to the highly varying background because of naturally occurring radioactive material (NORM), and low signal-to-noise ratio (S/N) of spectral signal measured during one-second acquisition intervals. The objective of this work is to explore *supervised* machine learning (ML) algorithms for detection and identification of weak nuisances and anomalies events in the presence of highly fluctuating background. As an example, Figure 1 shows images of gamma counts obtained with NaI detectors placed on a mobile platform in a drive through portions of the city of Chicago. Gamma counts per second (CPS), which are integrated over the energy spectrum, are displayed on the city map with pseudo color. Brighter counts indicate larger number of total counts. As seen in the figure, there is significant fluctuation of gamma counts due to NORM in an urban setting.

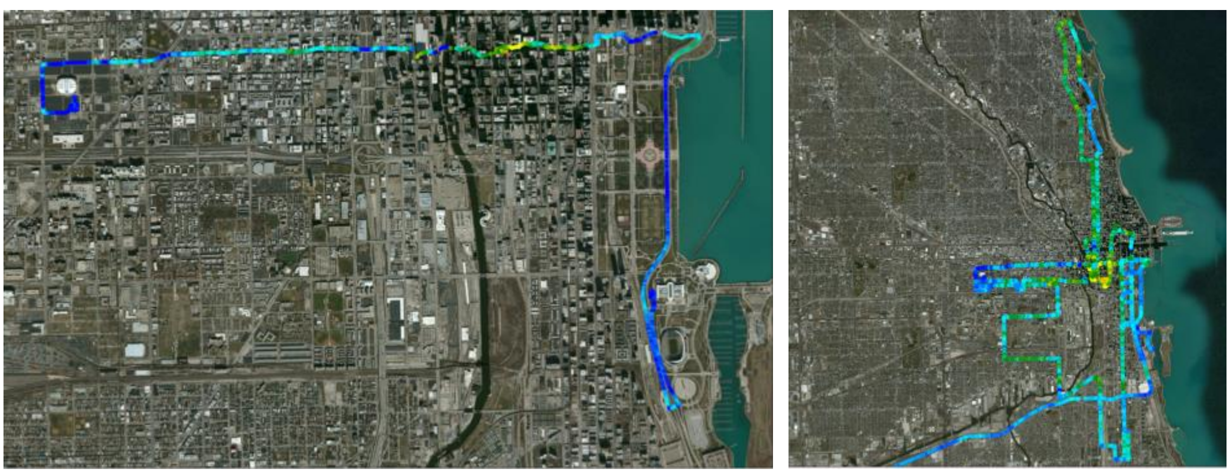

Figure 1 – Gamma counts, measured while driving with NaI detector through sections of the city of Chicago, displayed with pseudo color. Brighter colors indicate larger number of total counts.

In this work, we develop a Hopfield Artificial Neural Networks (HANN) in conjunction with an image processing algorithm to detect a weak signal anomaly hidden among the highly fluctuating background spectra. HANN is an associative memory algorithm inspired by the ability of a human brain to recognize objects from memory of past observations. The anomaly is the unstable orphan isotope that appears in the natural background consisting from gamma radiation by primordial isotopes. As part of HNN data analysis, the measurement 2D matrix is converted into an image, where the intensity of each pixel is given by counts per second (CPS).

2. Hopfield Artificial Neural Networks for Anomaly Detection

2.1. Hopfield Artificial Neural Network (HANN) Description

HANN is an associative memory algorithm inspired by human brain ability to learn from observations. The brain consists of neurons transmitting signals through the nervous system. The transmitting part of neurons are axons, which are long thin structures in which action potentials are generated. The receiving part of a neuron is a dendrite, which receives synaptic inputs from axons. The total sum of dendritic inputs determines if the neuron will fire an action potential [4]. HANN is a recurrent artificial neural network and a type of spin glass or Ising model, which provides model for understanding human memory [4]. HANN contains artificial neurons, which are binary threshold units, with the values of the states depending on unit's input exceeding its threshold. The interactions between neurons take values of 1 or -1 synaptic weights. Information is delivered to the next neuron that can be an output neuron or a process neuron. HANN implements an auto-associative memory by interconnecting each artificial neuron with all others, but not with themselves. The interactions of HANN neuron's are learned through Hebbian law of association [4], which provides a method to model memory for image reconstruction and pattern recognition. The weight matrix W matrix, calculated in Equation (1), is the sum of each independent weight of each neuron. Here *x* represents the training mode of the input vector.

$$W = \sum_{i}^{N} x_i * x_i^T \tag{1}$$

Discrete HNN has two ways to update and retrieve a memory pattern. The first one is asynchronous, which consists of updating one neuron at time until the system converges to a desire output. This is a very efficient method when the memory storage requires several samples to be memorized, but slows down the processing time of the system. The second one is synchronous, in which all neurons fire at once. Updating the system, we repeat the process several times until system converges to the desired output. Equation 2 describes these processes, where Y is the output, x is the input, and ξ represents a distorted input.

$$Y = sgn(W * \xi^T) \tag{2}$$

The weight matrix contains the memory patterns, which is used to retrieve the desire data by inputting the test data and iterate the neural network from state to state until it retrieves the correct pattern. This response is accomplish by the feedback characteristic of the system that allows the output to correct itself by iteration through the system until convergence. The diagram of a HANN is depicted in Figure 1.

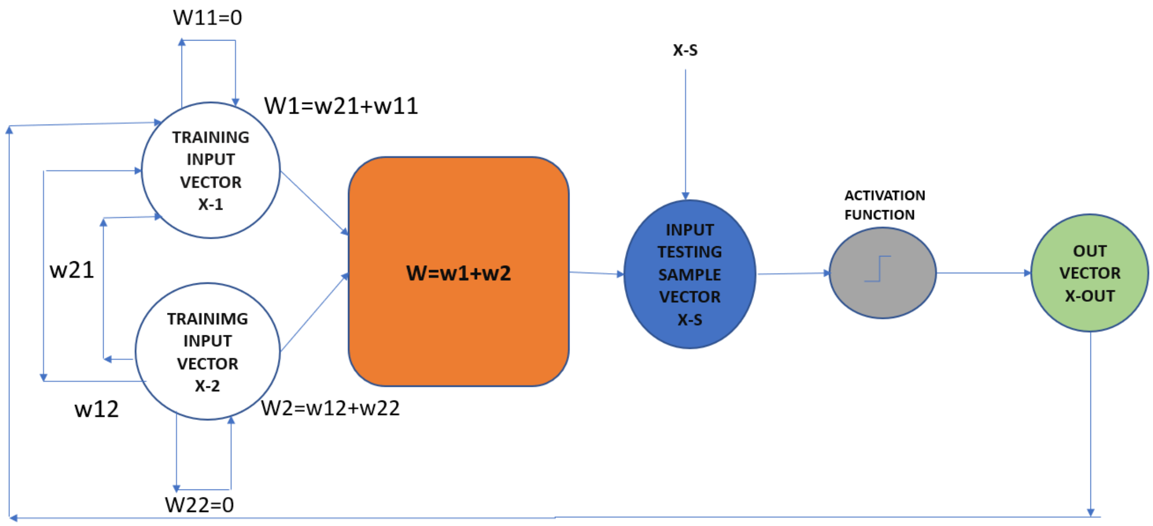

Figure 2 – Hopfield Artificial Neural Network structure

2.2. Image Processing Algorithm for Gamma Spectroscopy in Search Survey

Interactions between HANN neurons have units that take on values [1,-1]. To use HANN on a data set requires conversion of data to binary threshold HANN units. This is accomplished by converting original data into a grayscale intensity image, thresholding and normalizing the data to the set of binary values [1,0], and then converting the zero values to -1's. This process is illustrated in Figures 3 and 4. An example of grayscale intensity image of counts per second (CPS) for various energies and times is shown in Figure 3. The data set consists of 5827 one-second measurements of gamma spectra with NaI(Tl) detector-spectrometer with 1024 spectral channels and energy bandwidth from 0 to 3000keV. Grayscale intensity image of CPS is plotted with MATLAB.

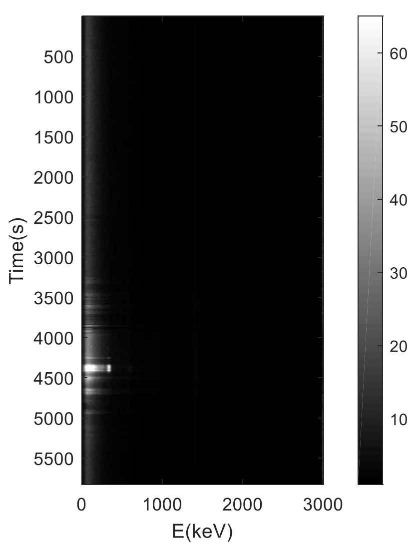

Figure 3 – Grayscale image of gamma counts per second (CPS)

3. Conclusions

We have investigated a Hopfield Artificial Neural Networks (HANN) together with an image processing algorithm to detect a weak signal anomaly hidden among the highly fluctuating background spectra. HANN is an associative memory algorithm inspired by the ability of a human brain to recognize objects from memory of past observations. The anomaly is the unstable orphan isotope that appears in the natural background consisting from gamma radiation by primordial isotopes. As part of HNN data analysis, the measurement 2D matrix is converted into an image, where the intensity of each pixel is given by counts per second (CPS).

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